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Making manufacturing flexibility operational – part 2: distinctions and an example

Carl-Henric Nilsson and Håkan Nordahl

Develops further the theories behind the framework for manufacturing flexibility presented in part 1 and works through an example

Introduction

Shorter product life cycles and the need to ensure the customer's demand for the company's products has brought into focus the manufacturing function in the corporate strategic process. The ability to respond to changing circumstances has become increasingly important, thus, the flexibility of the manufacturing function is of crucial importance to companies in many industries. In addition, time is becoming an increasingly important competitive factor, from initial invention, through engineering and manufacturing, to the distribution of the product into the market. It is thus evident that flexibility in manufacturing is an important issue and is expected to become even more important in the future[1].

The variety of flexibility definitions has caused the term to lose some of its usefulness. In order to analyse flexibility, the phenomena behind the concept must be brought forth. The flexibility concept has different meanings for different people, therefore, a large variety of aspects are discussed in the literature (e.g. [2-5]). Mandelbaum[6] defines flexibility as "the ability to respond effectively to changing circumstances". It is this definition that we use as a starting point for the structuring of the concept of flexibility.

Several of the contributions concerning flexibility in manufacturing have a limited view of the issue. Many articles are mainly directed at classification systems. Several also make constraints concerning the scope of manufacturing flexibility. The realms of flexibility need to be probed more thoroughly, beyond the classification systems, in order to explore the phenomena behind the concept. A systematization for handling flexibility-related issues in companies is presented in "Making manufacturing flexibility operational

– part 1: a framework" published in the last issue of *IMS*[7]. The framework's objective is to focus the efforts on the important issues of flexibility from a strategic viewpoint, thus leaving behind the discussion on classification systems. Three generic dimensions, inherent in all issues related to flexibility, are used in the framework for manufacturing flexibility.

The objective of this article is to develop further the theories behind the framework for manufacturing flexibility initially presented in our previous article[7]. More specifically we will:

- provide a conceptual structure of flexibility; and
- describe the use of the framework for manufacturing flexibility by working through a concrete example.

Frame of reference

The concept of flexibility is of paramount importance for the manufacturing function. Flexibility is discussed in terms of the elements in the chain: strategy – manufacturing strategy – manufacturing. For strategy, we rely on the work of Michael Porter[8,9] concerning competitive strategy and competitive advantage. The value system[9] connects the suppliers with the company and onward to the customers. Within the company, activities are related in a similar manner, creating the value chain. One objective of the company is to align and interconnect the value chain with the value system.

The predominant reference for manufacturing strategy is the work of Hill[10]. Hill highlights the importance of the manufacturing function and argues that manufacturing strategy should be an integral part of the corporate strategic process. Considering the fact that manufacturing accounts for 70-80 per cent of assets, expenditure and people [10, p. 19], the importance of the manufacturing function

should be evident. Chambers[11] shows how to connect manufacturing strategy to flexibility by outlining a framework that aligns flexibility with the elements of Hill's strategy model.

The frameworks mentioned are helpful both at the strategic level and at the manufacturing strategy level. However, few scholars go into detail as to *how* to make the frameworks operational in manufacturing. Our framework is developed to fill this gap and supplement the frameworks of Porter, Hill and Chambers.

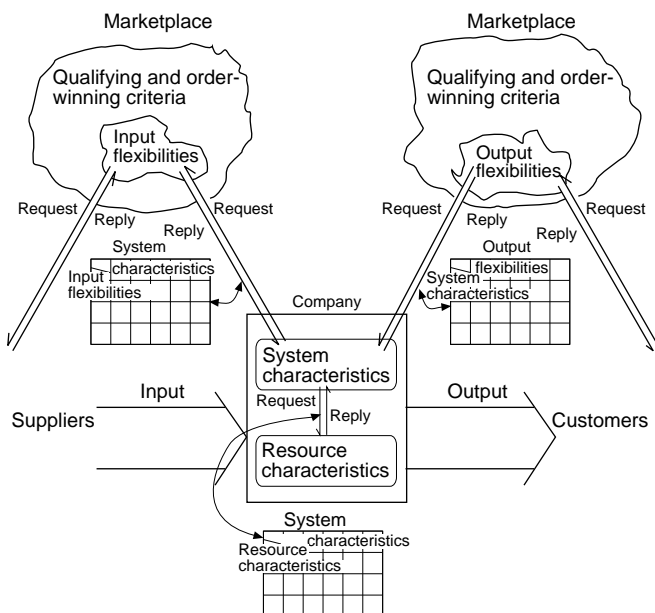
The framework

The construction of the framework for manufacturing flexibility is presented and described in detail in our previous article[7]. The framework for manufacturing flexibility consists of three distinct levels:

- (1) The strategic level – external flexibilities are defined in the marketplace between the company and its suppliers or customers.
- (2) The production system level – the characteristics of the production system are defined on a tactical level.
- (3) The production resource level – the resource characteristics are defined on an operational level.

Figure 1 shows the two levels of flexibility characteristics inside the company: resource and system. The figure also reveals the relationships of the system characteristics to the external flexibility on both the input and output side. The levels are interconnected by the request and reply for flexibility. The interconnections can be viewed as transformation matrices which transform aspects of flexibility on one level to the next. Depending on whether a top-down or

Figure 1. *The framework*



bottom-up approach is used, the matrices will focus on request or reply.

The model resembles a link in a chain and implies that the company should seek to obtain consistency with the other links of the chain. A chain is no stronger than its weakest link. In real life, the chain, from the first supplier to the final customer, can be long. Our suppliers have suppliers and our customers have customers, etc. The longer the chain, the more complex the relationship. However, a complex chain can always be reduced to single suppliers – company – customers units.

Distinctions of flexibility

Figure 2 shows the framework with the three levels of flexibility and the company's relationship in the value chain. The figure reveals that flexibility exists in four domains within the framework (shaded areas). The domains are described in the first dimension of flexibility ((1) in the Appendix). Whether flexibility is used to its full potential is described in the second dimension ((2) in the Appendix). Flexibility is also translated between the four domains. The third dimension ((3) in the Appendix) describes this interconnecting dimension of flexibility.

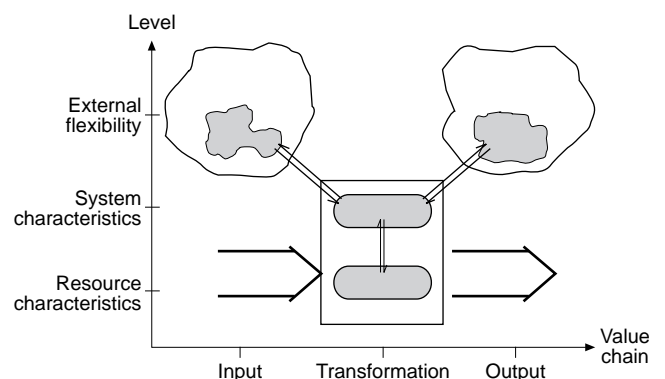
The framework rests on specific definitions, or distinctions, of the concept of flexibility in three generic dimensions, as defined in the Appendix.

Utilizing the framework

An objective of the company is to align the transformation process with the market strategy. The characteristics of the production system have to correspond to the external flexibility. Another way of stating this is that:

- external flexibility (input and output) is *what* the customers demand from their suppliers and what the suppliers can supply; while
- characteristics (system and resource) are *how* a company, internally, can accommodate its production facilities in order to fulfil the demand for external flexibility.

Figure 2. *A view of the framework in principle*



When we begin the analysis of a company we may choose any starting point. The links of the chain are all interdependent, therefore, the analysis must become iterative. When all the parts of the model are analysed, the process must be re-run in order to ensure that accommodations in the latter steps do not necessitate changes in the earlier steps. A beneficial approach in some cases can be a gap methodology. First, the current state of flexibility is determined, then the required state of flexibility is defined and finally, the gap is analysed and action taken to reduce it. To illustrate the use of the framework, an example is worked through.

An example

Background: The company is a single business company and all products are treated simultaneously in the same flexibility framework. The company's products are gear wheels in dimensions ranging from 38-198mm in diameter. Numerous variants are available which prohibit production to stock. The products are delivered in batches of at least 500 units to a few large customers. The demand is 4,700 units per month, evenly distributed in size.



Flexibility is an important aspect when choosing among investment alternatives

A flexibility audit, using the framework for flexibility, was performed earlier when the line of products was initially introduced. The potential output flexibilities, potential system characteristics, potential resource characteristics and potential input flexibilities are thus determined.

The current state of flexibility according to the last audit

Potential output flexibilities

These are shown as follows:

- Product flexibility – small (38-80mm diameter) and medium (80-198mm diameter) gear wheels can be manufactured.
- Mix flexibility – the two transfer lines (small and medium) are each dedicated to producing small or medium gear wheels, respectively.
- Volume flexibility – each transfer line can produce 2,500 gear wheels per month.
- Delivery flexibility – delivery time is between five and ten days.

Potential system characteristics

The crucial production system characteristics were earlier perceived and appraised as:

- Capacity – 5,000 gear wheels per month. No excess capacity is available.
- Physical sizes – diameter 38 to 198mm.
- Batch sizes – minimum 400 units.
- Total lead time – ten days.

Potential resource characteristics

The crucial production resource characteristics were earlier perceived and appraised as:

- Multi-product machines – the two transfer lines can only produce within their ranges: (small: 38-80mm, medium: 80-198mm).
- Set-up times – six hours in both transfer lines.
- Labour skills – the employees have the necessary skills to meet the current production. A majority of the employees can run all existing machinery.
- Material handling system – is fully compatible with current product range.

Potential input flexibilities

These are shown as follows:

- Product flexibility – all standard profiles, 3mm to 500mm diameter, of all standard materials are available.
- Mix flexibility – normally all profiles are in stock.
- Volume flexibility – well above the company's requests.
- Delivery flexibility – two weeks delivery time.

Current issue: a new large customer requests gear wheels ranging from 50-250mm diameter at a rate of 1,000 units per month, distributed over the range. Furthermore, they request smaller batch sizes of 50 units per batch. The customer is assessed to be very interesting for the company in the long term. The effect of the new request for flexibility is analysed in the framework for manufacturing flexibility to determine the appropriate reply. The framework is used in a top-down mode. Changes in one domain are translated by the translation matrices to determine the effects on the next level. The matrices are, in the top-down mode, worked through, first column by column, and second row by row. Iterations may be necessary in each domain as well as between the domains. The details of the process are, in the following, described just enough to make the line of reasoning of the first iteration clear. The squares are marked as follows:

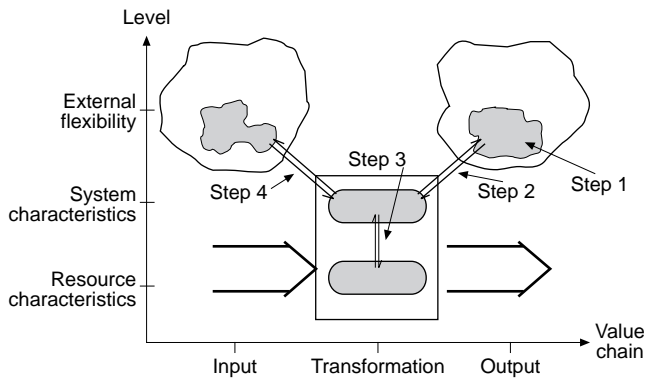
- OK = the link between levels is sufficient;
- fix = the link cannot be changed;
- = the link is not of primary relevance;
- ? = the link needs to be re-evaluated.

Steps for utilizing the framework are shown in Figure 3.

Step 1 – gap in output flexibilities:

- Product flexibility – the range must be increased to include larger gear wheels (198-250mm diameter).

Figure 3. The steps for utilizing the framework



- Volume flexibility – the volume of the company’s product increases by 1,000 units per year, evenly distributed over the range 50-250mm diameter.
- Mix flexibility – the capacity for different sizes (Table I).

Step 2 – output flexibilities to system characteristics (see Figure 4):

- (1) The product range must be expanded to include larger gear wheels (198-250mm diameter).
- (2) The requested mix flexibility will imply an increased capacity for all segments (small, medium and large). (See Table I.)
- (3) Batch sizes of 50 units must be feasible for all segments.
- (4) The total capacity must be increased. (See “Gap” in Table I.)

Conclusions for system characteristics:

- (5) The monthly capacity of each segment must be increased as follows: small – from 2,500 to 2,550, medium – from 2,500 to 2,900 and large – from 0 to 250.
- (6) The production system must be able to handle gear wheels in the span 38-250mm diameter.

- (7) Batch sizes for parts of all segments must be decreased to 50 units per batch.

Step 3 – system characteristics to resource characteristics (see Figure 5):

- (8) The capacity must be increased.
- (9) The material-handling system must be able to handle the increase in total volume.
- (10) The product range must be increased.
- (11) The current lines have no multi-product capabilities.
- (12) The equipment must be able to handle the new heavy segment.
- (13) The set-up time for the additional capacity must be less than one hour in order to handle small batch sizes.

Conclusions for resource characteristics:

- (14) New equipment is needed.
- (15) It would be preferable if the new machinery had multi-product capabilities in order to allow for more flexible shopfloor scheduling.
- (16) The set-up time for the additional capacity must be less than one hour in order to handle smaller batch sizes.
- (17) The higher total volume and the new segment means that the number of carriers as well as the size of each carrier must be increased to fit the larger gear wheels.

Step 4 – System characteristics to input flexibilities (see Figure 6).

Conclusions for input flexibilities:

- (18) When all the factors affecting the capacity of the production system from the input side, are taken into consideration, the current input flexibilities are fully compatible with the changes in the system characteristics.

Table I. Monthly volumes per segment

	Current capacity	Current production	New request	Gap
Small (38-80mm diameter)	2,500	2,400	150	50
Medium (80-198mm diameter)	2,500	2,300	600	400
Large (198-250mm diameter)	0	0	250	250
Total	5,000	4,700	1,000	700

Figure 4. *The relationship between the output flexibilities and the system characteristics of the production system*

System characteristics \ Output flexibilities ^a	Product flexibility Small, Medium Large	Mix flexibility Full mix	Volume flexibility S: 2,550, M: 2,900, L:250	Delivery flexibility Ten days	Conclusions
Capacity	–	2 ?	4 ?	–	5 ?
Physical sizes	1 ?	–	–	–	6 ?
Batch sizes	–	3 ?	–	–	7 ?
Total lead-time	–	OK	–	OK	OK
Conclusions	?	?	?	OK	

Note: ^aThe chosen output flexibilities and their definitions are contingent on the company. The four chosen categories are used as an example

Figure 5. *The relationship between system characteristics and the resource characteristics of the production system*

	System characteristics \ Resource characteristics	Capacity S: 2,550, M: 2,900, L: 250	Physical size 38-250mm diameter	Batch sizes 50 units	Total lead time ten days	Conclusions
Machines	Capacity	8 ?	10 ?	–	–	14 ?
	Multi-product capabilities	–	11 ?	–	OK	15 ?
	Set-up times	–	–	13 ?	OK	16 ?
Labour	Labour skills	OK	OK	–	OK	OK
Infrastructure	Material handling systems	9 ?	12 ?	OK	OK	17 ?
Conclusions		?	?	?	OK	

Step 5 – actions for change: The production system must be increased in capacity as well as product range. At least two options are available to the company:

- (1) Rebuild the current lines to increase capacity as well as product range. The set-up times must be substantially reduced in order to comply with the smaller batches.
- (2) Install an FMS cell with the capability of producing the entire product range (38-250 mm diameter), with capacity of 1,000 units per month and set-up times of less than one hour.

Irrespective of which solution is chosen, the material-handling system also has to be upgraded to handle the higher volumes and the larger gear wheels.

The conclusions from the flexibility audit are forwarded to the capital budgeting process. In the capital budgeting process, flexibility is an important aspect when choosing among investment alternatives. The framework for manufacturing flexibility can be useful in this process to determine the potential resources' impact on the system characteristics as well as output flexibilities. The framework is, in this case, used in a bottom-up mode in order to disclose the flexibility-related aspects inherent in the potential new machinery. In this example, for instance, the old equipment can continue to produce the larger batches while the new equipment will open up smaller batch production across the product range.

Figure 6. The relationship between input flexibilities and the system characteristics of the production system

System characteristics \ Input flexibilities	Capacity S: 2,550, M: 2,900, L: 250	Physical size 38-250mm diameter	Batch sizes 50 units	Total lead time ten days	Conclusions
Product flexibility	OK	OK	–	–	OK
Mix flexibility	OK	OK	–	OK	OK
Volume flexibility	OK	OK	–	–	OK
Delivery flexibility	–	–	–	OK	OK
Conclusions	OK	OK	OK	OK	18 OK

Discussion and conclusion

The objective of this article is twofold: to provide a conceptual structure of flexibility, and to describe the use of the framework for manufacturing flexibility by using a concrete example.

questions than it answers. This is however not due to the complexity of the framework, but to the complexity of the concept of flexibility itself. Flexibility is a concept full of nuances, some of which are being disclosed by just beginning to use the framework. The framework can simplify the work with flexibility, however it cannot simplify the concept itself.

When one starts to analyse flexibility, it seems to raise more questions

The conceptual structure of flexibility is made in order to provide the means of changing the cognitive structure in the researchers’ as well as the practitioners’ minds. The important issue of flexibility, theoretically, as well as in real life, is *not* to create a system of labelled boxes to put flexibility related aspects in. It is of minor interest to debate which box is the “right” box for a specific aspect. We propose that creating a fit between flexibility in the environment of the company and the characteristics of the company is the important issue. The structuring of flexibility in three generic dimensions provides a conceptual means of achieving this. A mutually agreed terminology can provide a basis for a common understanding of flexibility characteristics inherent in the company’s production, as well as, an understanding of flexibility in the company’s environment. The framework for manufacturing flexibility provides a means for connecting the external flexibilities and internal characteristics in order to reach concordance between all levels. The example shows *one* possible use of the framework. It can also be used in a bottom-up mode in order to disclose the effects on the output flexibility of characteristics inherent in potential new equipment. When one starts to analyse flexibility, using the framework for manufacturing flexibility, it first seems to raise more

The *raison d’être* of a framework rests on its usefulness. In order to be useful, at least two prerequisites must be fulfilled: the heart of the problem must be addressed, and the framework must be flexible enough to allow the user to make contingent adjustments to the framework when using it, yet be robust enough not to fall apart when used. The framework for manufacturing flexibility is created with this in mind, allowing for individual adjustments and contingent utilization.

The framework demands a lot of work, that is true. Unfortunately, there is no easy way to achieve insight into the flexibility issue without investing time and work. The pay-off of using the framework can, however, be huge. It provides a means for developing strategies in the company, relating the company’s production system to the company’s environment. The process of developing the strategies also provides rich opportunities for integrating the strategies within the organization.

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- External flexibility is flexibility in the relationship between the company and the context outside the company. It is divided into two groups: output flexibility, which exists in the relationship between the company and its customers, and input flexibility, which exists in the relationship between the company and its suppliers.
 - Internal flexibility, flexibility characteristics or, for short, characteristics – the terms are equivalent – is flexibility which is located within the borders of the company. It is divided into two levels: system level and resource level. System characteristics are the inherent properties of the production system on an aggregated level. Resource characteristics are the inherent properties of the individual components of the production system. These components can be divided into three broad groups: machines, labour and infrastructure.

(2) *The second dimension* of flexibility makes the distinction between the potential flexibility of each domain and the flexibility that is utilized:

- Utilized flexibility is the inherent flexibility that is used.
- Potential flexibility is the flexibility that is inherent but not used.

(3) *The third dimension* of flexibility connects the flexibilities between different domains:

- Requested flexibility is the demand for flexibility from one domain to the next.
- Replied flexibility is the flexibility supplied from one level to the next, responding to the request.

Appendix: the generic dimensions of flexibility

Flexibility is "the ability to respond effectively to changing circumstances"[6].

- (1) *The first dimension* of flexibility describes the levels of the flexibility in the model: